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Proposed Performance Evaluation Acceptance Test for Heat Recovery Incinerators

by
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The test procedure is applicable for the capacity range from 20 to 100 tons per day (18 to 91 tonne/D). The throughput capacity of the heat recovery incinerator (HRI), volume and mass reduction, environmental emissions, and overall thermal efficiency are used as performance indicators.

Equipment literature from HRI manufacturers was reviewed to determine the characteristics manufacturers use to describe their HRIs, and to define and understand general operating procedures and conditions. The American Society of Mechanical Engineers (ASME) Power Test Codes were reviewed to see if they could be used for HRI testing. The proposals for thermal efficiency testing presented at several past ASME National Waste Processing Conferences were also reviewed. Four efficiency test methods—the input-output, heat-loss, modified heat-loss, and calorimeter methods—were identified from this information. An alternate concept of separate combustion efficiency and thermal energy recovery testing was also identified.

It is recommended that the input-output method be used as the basis of the acceptance test procedure, the heat-loss method be used to isolate the areas of inefficiencies should losses be excessive, and the modified heat-loss method be used for routine monitoring of the system.

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It is recommended that the input-output method be used as the basis of the acceptance test procedure, the heat-loss method be used to isolate the areas of inefficiencies should losses be excessive, and the modified heat-loss method be used for routine monitoring of the system.

FOREWORD

This study was performed for the Office of the Chief of Engineers (OCE) by the Energy Systems (ES) Division, U.S. Army Construction Engineering Research Laboratory (USA-CERL). The work was completed under Project 4A762781AT45, "Energy and Energy Conservation"; Task D, "Solid Fuels Application Strategy"; Work Unit 001, "Application of Solid Fuels by Direct Combustion." Mr. B. Wasserman, DAEN-ZCF-U, served as the OCE Technical Monitor. Mr. K. E. Griggs was USA-CERL's Principal Investigator. Dr. G. R. Williamson is Chief of ES. The Technical Editor was Gloria J. Wienke, Information Management Office.

A preliminary version of this study was performed under contract by Camargo Associates, Cincinnati, OH. Camargo personnel directly involved were Mr. J. W. Boylan and Mr. G. M. Showers.

COL Carl O. Magnell is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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PROPOSED PERFORMANCE EVALUATION ACCEPTANCE TEST FOR HEAT RECOVERY INCINERATORS

1 INTRODUCTION

Background

The Resource Conservation and Recovery Act of 1976 recommended the use of recovered-material derived fuels (RDFs) to the maximum extent practical in federally owned fossil fuel fired energy systems. To fulfill the intent of this act and to take advantage of possible energy cost savings, the Army has undertaken the task of installing heat recovery incinerators (HRIs) at various installations throughout the Continental United States (CONUS). The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has developed planning guidance for such HRI installations.[1] Currently, HRIs are operational at Fort Dix, NJ, Fort Eustis, VA, Fort Leonard Wood, MO, Fort Rucker, AL, and Redstone Arsenal, AL, but waste may be burned at more than 15 Army installations by 1995.

Unlike other large-scale equipment, such as coal or oil fired boilers, no standard performance test is available to assess field performance or to use as an acceptance test for the HRI plants being built. Installation Directorates of Engineering and Housing (DEHs) and District Engineers need a standard acceptance test to troubleshoot HRI systems and to ensure that new HRIs meet waste throughput and efficiency specifications before they are turned over to the DEH for operation.

Objective

The objective of this research was to establish and evaluate a procedure for assessing the performance of HRIs in terms of thermal efficiency, weight and volume reduction, environmental emissions, and throughput capacity and reliability. This test procedure is designed for use by District Engineers and/or DEHs when accepting new HRIs or evaluating existing ones.

Approach

HRI manufacturers were contacted to obtain literature describing their incinerators. The literature was reviewed to determine the characteristics manufacturers use to describe their products, and to define and understand general operating procedures and conditions. The American Society of Mechanical Engineers (ASME) Power Test Codes

[1] S. A. Hathaway and R. J. Dealy, *Technical Evaluation of Army-Scale Waste-to-Energy Systems*, Interim Report E-110/ADA042578 (USA-CERL, July 1977); S. A. Hathaway, *Recovery of Energy from Solid Waste at Army Installations*, Technical Manuscript E-118/ADA044814 (USA-CERL, August 1977); S. A. Hathaway, *Application of the Package Controlled-Air, Heat Recovery Solid Waste Incinerator on Army Fixed Facilities and Installations*, Technical Report E-151/ADA071539 (USA-CERL, June 1979).

(PTC 4.1 AND PTC 33) were reviewed to see if their information could be used for HRI testing.* The Naval Civil Engineering Laboratory (NCEL) procedures for HRI testing (unpublished) were also reviewed for applicable information.

It was determined that the basis, or core, of the acceptance test should be the repeated ability to demonstrate that the unit will operate at the specified thermal efficiency while simultaneously achieving the rated throughput capacity, weight and volume reduction, steam (or other thermal) output, and environmental emissions. While thermal efficiency (the ability to release the theoretical heat energy available in a useful form) cannot be the sole criterion for acceptance, it is the best single indicator of the correctness of design and quality of manufacture. Four test procedures identified from the above-referenced sources--the input-output, heat-loss, modified heat-loss, and calorimeter methods--were evaluated for use as the basis for the acceptance test. An alternate concept of separate combustion efficiency and thermal energy recovery testing was also evaluated.

Scope

The acceptance test developed during this research is for HRIs in the range of 20 to 100 tons per day (TPD) (18 to 91 tonne/D) of solid waste. Tests for compliance with clean air requirements are defined by local, State, and Federal agencies. New HRIs should meet stipulated capacity, volume and weight reduction, and efficiency guarantees while simultaneously operating in compliance with clean air requirements. Therefore, these test procedures must be conducted concurrently with environmental testing to assure compliance with air emission standards during normal operation.

No matter how rigorous an acceptance test is, the performance standards that the HRI is required to meet must be clearly and completely defined in the project specifications. This acceptance test is intended to support Corps of Engineers Guide Specification CEGS-11171, *Incinerators, Packaged Controlled Air.*** The test will not prevent or correct problems that previous HRI projects have encountered. However, the test procedure described in this report will reveal and document the existence of these problems.

Mode of Technology Transfer

It is recommended that the test plan be incorporated into construction contract documents by modifying the project guide specification, CEGS-11171, to include either the complete acceptance test or a reference to the test.

*See Appendix A for a list of the ASME and American Society for Testing and Materials (ASTM) publications used in the performance test.

**See Appendix A for a list of the Corps of Engineers Guide Specifications (CEGS), Military Specifications, American National Standards Institute, Underwriters Laboratory, and Environmental Protection Agency publications related to acceptance testing.

2 THERMAL EFFICIENCY TEST METHODS

The acceptance testing of an HRI is a very complex issue due to both the variable quality of the refuse (heat content versus moisture and noncombustibles) and the variety of technologies to burn it, some of which are still developing. The question of an appropriate and accurate HRI acceptance test is a matter that has been discussed at ASME National Waste Processing Conferences.[2] The simplest acceptance test would be to see if the HRI could produce the rated amount of steam when firing the rated amount of refuse and supplementary fuel (if required). Unfortunately, this does not take into consideration possible variations in the heat content (Btu/lb [British thermal units per pound]) of the waste, which may allow a poorly operating unit to still make its rated steam output (high Btu waste) or may prohibit a well operating unit from making its rated steam output (low Btu waste). Most researchers agree that thermal efficiency is the best indicator of performance quality, since it takes into consideration the heat content of the waste.

Researchers have not directly addressed the problem of how much the thermal efficiency of the various HRI technologies may change due to "off design" operation as a result of burning waste of a quality other than that specified. The main controversy seems to be the method (and the degree of effort) that should be the standard in determining thermal efficiency. Much of this controversy is prompted by the difficulty in determining the higher heating value (HHV) of the waste. Various proposals have attempted to minimize the effect of this uncertainty. Very little effort has been made to develop automated equipment to more economically and accurately determine the waste HHV. The National Bureau of Standards (NBS) has developed a calorimeter for "large" (kilogram size) RDF pellets. However, the methods for determining waste HHV are still very labor intensive and involve collecting and processing large amounts of waste to achieve a reasonable accuracy.

Thermal efficiency cannot be the sole criterion for acceptance, although it may be the core of testing. The plant must also reliably process the design amount of waste, produce acceptable environmental emissions, and discharge ash that exhibits the desired volume and mass reductions. With the exception of thermal efficiency, all of the above criteria have very specific and well defined methods of being measured. USA-CERL researchers recommend that an acceptance test consist of three 24-hr runs conducted within 5 days to demonstrate reliability. The runs can be consecutive.

The thermal efficiency test methods described in this chapter can serve two purposes. First, they may be used as the basis of an acceptance test to establish whether

[2]G. Stabenow, "Predicting and Testing Incinerator-Boiler Efficiency . . .," *1980 ASME National Waste Processing Conference* (Washington DC, May 1980), pp 301-313; R. Hecklinger and L. Grillo, "Thermal Performance Evaluation of MSW Fired Steam Generators . . .," *1982 ASME National Waste Processing Conference* (New York, NY, May 1982), pp 65-69; A. Beckman and M. Dragovich, "Calculating Efficiency of Municipal Waste Mass Burning Energy Recovery Systems," *1984 ASME National Waste Processing Conference* (Orlando, FL, June 1984), pp 217-229; J. Fernandes, "Uncertainties and Probable Errors Involved in Various Methods of Testing Incinerator/Boilers," *1984 ASME National Waste Processing Conference* (Orlando, FL, June 1984), pp 230-240; K. Griggs, "An Examination of Proposed Acceptance Testing Methods," *1986 ASME National Waste Processing Conference* (Denver, CO, June 1986), pp 233-239.

a system meets the capacity, volume and mass reduction, and efficiency criteria of the specification under which it was purchased. Second, they can be used as a periodic performance evaluation to indicate if and when high inefficiencies are occurring. In this second instance, the test is conducted regularly and the information is compared with that from previous tests. Reduced thermal efficiency may also indirectly indicate the possibility of environmental emission problems. This comparison may be made because of the common procedure and data base.

Test Methods

To accomplish efficiency testing, four methods and an alternate concept of separate combustion efficiency and thermal energy recovery testing have been identified. The primary methods are the input-output, the heat-loss, the modified heat-loss, and the calorimeter methods, as described below. (A more extensive review of the equations, theory, and assumptions for the calculations is in Appendix B, and Appendix C contains related symbols, definitions, and metric conversions.)

Input-Output Method

$$\text{Thermal efficiency (\%)} = \frac{\text{Useful Heat Output}}{\text{Heat Input}} \times 100 \qquad \text{[Eq 1]}$$

Useful Heat Output is the heat absorbed by the heat recovery fluid and by useful cooling water and Heat Input is the heat released by the combustion process, based on the higher heating value of the waste and supplemental fuels.

Figure 1 illustrates the flow of heat into and out of the incinerator system, and the heat flow measurements required in the input-output calculations.

Appendix D contains data/calculation sheets for the input-output method. Appendix E contains an example of the test results using the input-output method. Values listed are considered typical for a 25 TPD starved air HRI.

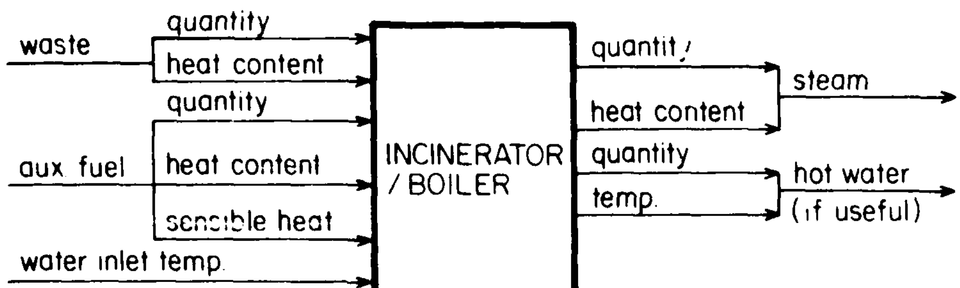


Figure 1. Input-output method.

Heat-Loss Method

$$\text{Thermal efficiency (\%)} = \left(1 - \frac{\text{Losses}}{\text{Heat Input}}\right) \times 100 \qquad \text{[Eq 2]}$$

Heat Input is the heat released by the combustion process, based on the higher heating value of the waste and supplemental fuels and Losses is the heat released by the combustion process but not absorbed by the working fluids.

The most rigorous form of this test method attempts to measure all losses and minimize any estimates.

Figure 2 illustrates the flow of heat into and losses out of the incinerator system, and the heat flow measurements required in the heat-loss calculations. Since this method has not been recommended to be part of the acceptance test, the details of the calculations are only included in Appendix B.

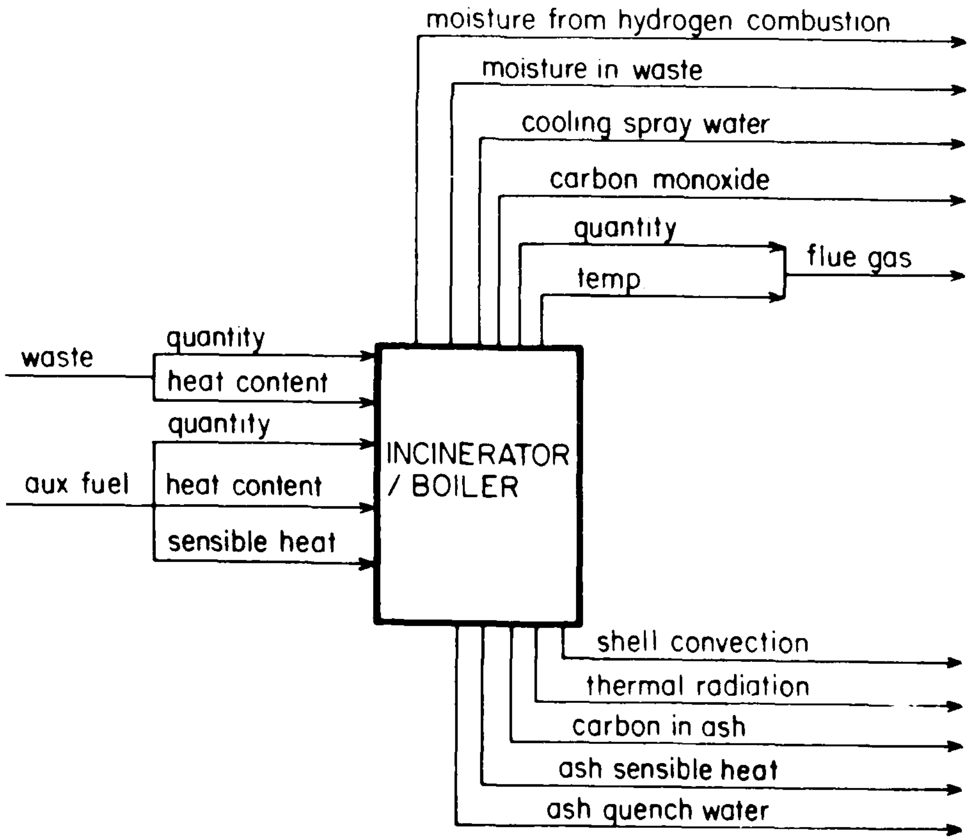


Figure 2. Heat-loss method.

Modified Heat-Loss Method

$$\text{Thermal efficiency (\%)} = \left(1 - \frac{\text{Major Losses}}{\text{Heat Input}}\right) \times 100 \qquad \text{[Eq 3]}$$

Major Losses is normally considered to be the heat lost up the stack and sometimes the heat lost through unburned carbon in the ash. All other losses are estimated. Otherwise, this method is the same as the regular heat-loss method. Since this method has not been recommended to be part of the acceptance test, the details of the calculations are only included in Appendix B.

Calorimeter Method

$$\text{Thermal efficiency (\%)} = \left(\frac{\text{Useful Heat Output}}{\text{Useful Heat Output + Losses}}\right) \times 100 \qquad \text{[Eq 4]}$$

Useful Heat Output and Losses are as described in the input-output and heat-loss methods, respectively. This method attempts to solve the problems associated with determining the heat content of the waste fuel in order to determine the heat input. Figure 3 illustrates the flow of heat into and losses out of the incinerator system

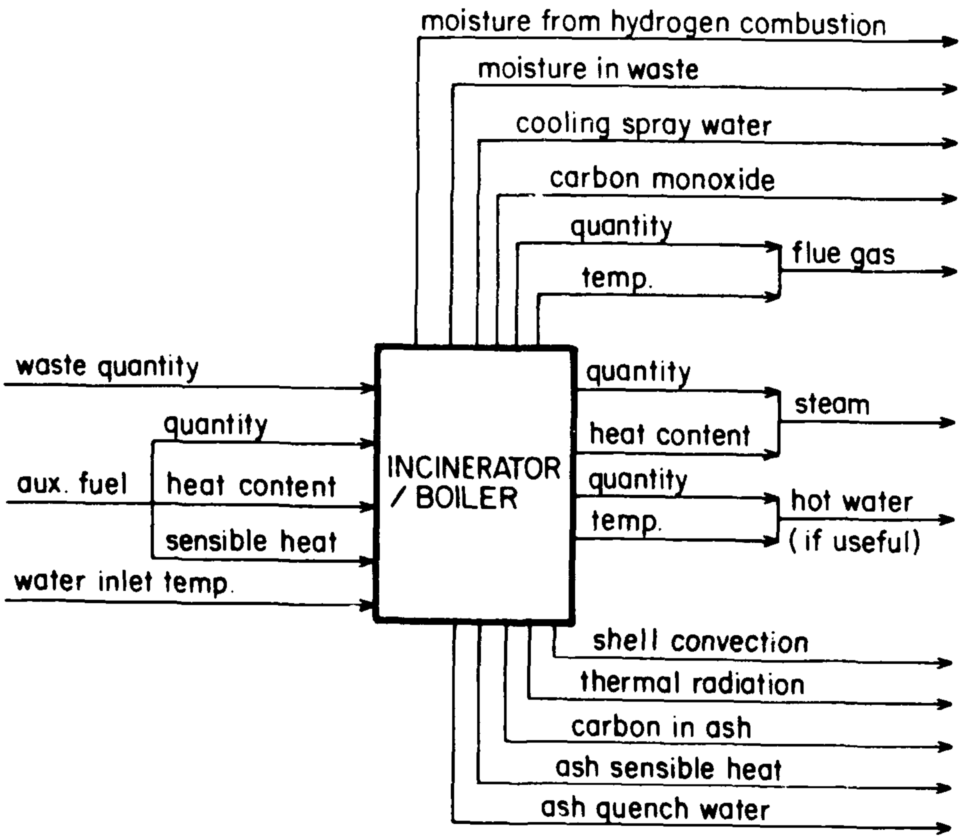


Figure 3. Calorimeter method.

required in the calorimeter calculations. Since this method has not been recommended to be part of the acceptance test, the details of the calculations are only included in Appendix B.

Alternate Concept

The alternate concept involves testing the boiler (separate or integral) by delivering to it the rated amount of hot gases at the specified temperature and measuring its thermal efficiency by conventional methods. These hot gases would be produced by conventional firing of gas or oil. The efficiency of the incinerator itself would be measured only by determining the amount of carbon in the ash as an indicator of completeness of combustion at the design firing rate.

Evaluation of Test Methods

The input-output method is the simplest of the four. Much of the instrumentation required by this method should already exist as a part of the system's normal operating controls. Moreover, there is a requirement for less data and laboratory analysis than with the other methods, except for the modified heat-loss method, which is also the least accurate. The only method that has the potential for more accuracy than the input-output method is the calorimeter method, which is also very complex.

While the heat-loss method is more difficult and potentially less accurate than the input-output method, its advantage is that it provides additional useful information. For example, if an incinerator system is not operating efficiently, this method should show where the excessive losses are (e.g., unburned carbon in the residue or high boiler exit gas temperature). Hence, this method is most valuable in identifying operating and maintenance problems, and is preferred by many engineers for all types of fossil fuel fired facilities.

The modified heat-loss method, while the least accurate, is sufficiently accurate for operational monitoring of the HRI. It is also quick.

The calorimeter method is much more complex than any of the other methods. It also has the potential for being the most accurate method, but that is contingent upon accurately determining the moisture in the flue gases. The potential improvement in accuracy over the input-output method is also not significant considering the size range and lack of sophistication of typical Army HRI plants. However, this method would be appropriate for large HRI plants with electrical cogeneration that the Army would be involved with on a "third party" basis.

In the alternate concept, the functioning of the incinerator and the heat content of the waste are not directly involved in determining the efficiency of producing useful thermal output. Unfortunately, incinerators are not normally supplied with startup and auxiliary (secondary zone) burners of sufficient size to produce the boiler's rated steam output without burning any waste. However, some manufacturers of modular starved-air systems do offer the option of a burner capable of full steam production in the event the incinerator ceases to function and steam output must be maintained. In those cases, this separate testing concept could be applicable.

Because of the accuracy, instrumentation, and data requirements, the input-output thermal efficiency test method is best suited as the basis of an acceptance test for new HRI systems of the size the Army would typically build.

3 ACCEPTANCE TEST PLAN

Acceptance testing is accomplished in three phases. Prior to the actual test, certain procedural arrangements, inspections, and some preliminary component testing (discussed below) must be completed. The actual test runs may then be accomplished. Finally, postoperation inspections and calculations based upon the test data must be performed.

Pretest Preparation

Date of Test

An acceptance test of a new HRI system should be conducted as soon as the HRI construction contractor has determined that the system is suitable for operation.

Test Personnel

The following test personnel must be permitted to witness any and all acceptance tests for new HRI installations:

Test Engineer: The individual supplied by the contractor to supervise the actual testing of the HRI and to assure compliance with this test procedure.

District Engineer: A representative of the U.S. Army Corps of Engineers District responsible for overseeing construction of the HRI.

Post Engineer: A representative of the installation DEH staff where the HRI is located.

Test Technicians: Individuals supplied by and under the supervision of the Test Engineer. These may be field representatives of the HRI manufacturer and/or representatives of the manufacturers of the other components and systems in the plant.

The Test Engineer shall notify the District and Post Engineers a minimum of 30 days before a proposed acceptance test date. During the acceptance test, the plant will be run by the operating personnel. However, the Test Engineer and any Test Technicians present should check the work of the operating personnel to ensure the correct operation of the equipment and to verify the adequacy of the operating personnel's training.

Test Outline

Before conducting the test, the Test Engineer will review the calculations and test data required. All deviations from these testing procedures must be noted by the Test Engineer and approved by the District Engineer before beginning the test.

System Operation

The Test Engineer shall provide the government representatives with written verification (i.e., copies of reports) that the following inspections and tests were conducted by the contractor prior to acceptance testing.

General. The contractor should inspect all materials, equipment, and components upon delivery to the job site to ensure compliance with the specifications before installation. The District Engineer may also conduct inspections upon delivery, during installation, and after installation. Prior to the plant acceptance tests, the HRI and all auxiliary equipment shall be operated by the contractor to ensure that the installation is complete, that all necessary adjustments have been made, and that the plant is ready for operation. In addition to the HRI manufacturer's field representative, factory-trained engineers or technicians employed by individual component suppliers should be present during the startup tests to ensure the proper functioning, adjustment, and testing of the individual components and systems. All labor, equipment, and test apparatus shall be furnished by the contractor. The contractor shall rectify all defects disclosed by the tests within the time period specified by the contracting officer.

Utility Systems. Test the domestic water system, the sanitary system, and storm drains in accordance with that section of the specification equivalent to CEGS 15400 *Plumbing, General Purpose.*

Test the interior electrical system and interior lighting in accordance with that section of the specification equivalent to CEGS 16415 *Electrical Work, Interior.*

Solid Waste (SW) Retrieval System. When equipped with an overhead crane, test this system in accordance with the test and safety requirements of American National Standards Institute (ANSI) publication B30.2, *Overhead and Gantry Cranes.*

Feedwater Equipment Tests. Test the feedwater treatment equipment to determine compliance with the limits for oxygen content and hardness concentrations of the specification equivalent to CEGS 11233 *Water Softeners, Cation Exchange.* All equipment for taking samples, and the test kit for analyzing the samples, shall be supplied by the contractor and shall revert to Government ownership when the tests are completed.

Fuel Oil System (when present). Before applying the test pressure, remove or valve off piping components that may be damaged by the test and install a currently calibrated test gauge. Maintain the test pressure for at least 1 hr. Locate and repair any leaks and repeat the test.

Piping test: Before backfilling the pipe trenches, perform a hydrostatic test of the piping with No. 2 fuel oil at 1-1/2 times the system pressure or 100 psig (pounds per square inch gauge) whichever is greater.

Steel Fuel Oil Storage Tanks: Field test the tanks in accordance with Method A of Manufacturing and Production Tests of Underwriters Laboratories (UL) 142, *Steel Aboveground Tanks for Flammable and Combustible Liquid.* Underground tanks shall be tested for leaks both before and after being placed in the trench. Makeshift repair (caulking) is not permitted for correcting leaks in tanks. Welding or brazing is permitted.

Fiberglass Reinforced Plastic Tank: Test in accordance with Military Specification MIL-T-52777, *Tanks, Storage, Underground, Glass Fiber Reinforced Plastic.*

Dust Collector. Test the system in accordance with the latest revisions of EPA 40 CFR Part 60, Appendix A, at the specified design conditions. The contractor shall furnish reports certifying that the instruments were calibrated and the indicated readings are true, the computations required for testing are accurate, acceptable methods were used, and the equipment satisfactorily performed in accordance with requirements.

Conveyors. Perform tests to determine the system's capability to convey given quantities and types of material in specified times. Overload and emergency stop tests shall also be performed in accordance with the Occupational Safety and Health Administration (OSHA) safety requirements.

Fire Protection System. Test the fire protection system in accordance with that portion of the specification equivalent to CEGS 16721, *Fire Detection and Alarm System* and CEGS 15501, *Sprinkler Systems, Fire Protection.*

Auxiliary Equipment. The contractor shall observe and check all blowdown valves, stop valves, try cocks, draft fans, fuel oil heaters, pumps, electric motors, and other accessories before the plant acceptance tests. The District or Post Engineer should doublecheck these items. Correct any leakage, malfunctions, defects, noncompliance with referenced standards, or overloading before testing begins.

Preliminary test runs must be conducted to verify proper operation of test instruments, acquaint Test Technicians with the equipment, and make any minor adjustments. These preliminary tests and adjustments are very important to a valid acceptance test. Before the test, the system must be in a steady mode of operation as verified by the government representative. The combustion conditions, quality and quantity of waste being fed, excess air, chamber temperature, gas temperature and pressure, and water and steam flows must be maintained as constant as possible during each test.

Depending upon the specific equipment involved, the HRI may have to be operated anywhere from 1 hr to 1 day before the tests to achieve a steady state. A steady steam demand may be achieved by venting steam to the atmosphere, or by requiring an associated fossil fuel plant to compensate for load fluctuations.

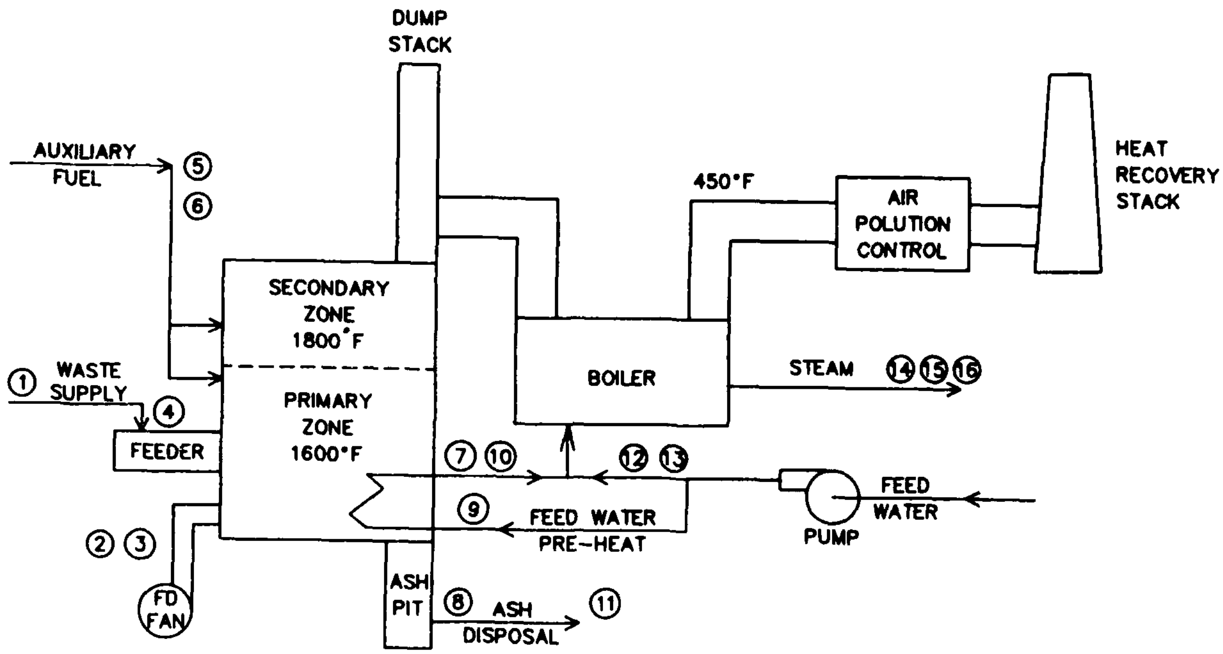
The entire incinerator system must be operated as near as practical to the waste flow rate, chamber temperature, underfire and excess air, and drum pressure given in the equipment specifications. This applies to the preliminary test run, to the pretest steady state mode, and to the performance or acceptance test itself.

Test Measurements

To the extent possible, the acceptance test uses the same instrumentation used for routine operation of the HRI facility. Use of any instrumentation other than that specified must be noted by the Test Engineer and approved by the District Engineer before testing. Each instrument should be checked for operability and accuracy before testing to ensure valid test data. Figure 4 illustrates the data recording locations and lists the test data required for the input-output method. Reject the test if there are serious inconsistencies in the observed data during the test or in later computational analysis.

Measurement Intervals

During the acceptance test, record the various required readings on the data sheets (Appendix D) at least once every 4 hrs, but no more often than once every 30 min. Because of the variability in the characteristics of the incineration equipment, more exact guidance for the frequency of data recording cannot be given. This subject may have to be negotiated with the contractor. The test consists of three 24-hr runs during a 5-day period. The runs can be consecutive. Use calibrated continuous recording



Key

1. Sample of waste
2. Dry bulb temp. of combustion air, °F*
3. Volume flow rate of combustion air, cfm
4. Mass of waste charged, lb
5. Volume flow of natural gas, cu ft
6. Mass flow of fuel oil, lb
7. Mass flow rate of cooling or preheat water, lb/hr
8. Mass of wet residue recovered, lb
9. Temp. of cooling or preheat water, °F
10. Temp. of cooling or preheat water--out, °F
11. Sample of wet residue
12. Mass flow rate of feed water, lb/hr
13. Temp. of boiler feed water, °F
14. Mass flow rate of steam, lb/hr
15. Temp. of steam, °F
16. Steam pressure, psia
17. Electric power consumption**
    a. 110V in-feed
    b. 480V in-feed
    c. Other

*Refer to Appendix C for metric conversions and definitions.
**Optional data for information only.

Figure 4. Data recording locations for the input-output method.

instruments as much as possible. Any continuous instruments for flow should include a flow integrator to show the total flow during the test period. Taking periodic instrument readings during each run will identify any malfunctions as soon as possible. The run can then be terminated, repairs made, and retesting may commence quickly.

Pressure Measurements

Take all pressure measurements in accordance with ASME PTC 19.2. Make all gauge connections as short and direct as possible and locate them where they will not be affected by extreme heat, cold, or vibrations. Calibrate all pressure gauges before installation.

Temperature Measurements

Take all temperature measurements in accordance with ASME PTC 19.3. Mercury-in-glass thermometers, resistance thermometers, or thermocouples are acceptable for temperatures up to 700 ^{o}F. Calibrate all temperature measuring devices before testing and install them so that they will not be affected by radiation or conduction. Make sure the heat receiving part of the instrument is not located in a dead pocket of the fluid being measured.

Solid Waste Measurements

The solid wastes charged in the incinerator must be representative of the material to be burned during "normal" operation. Mix wastes with various characteristics to achieve a consistent, uniform waste quality.

Incinerator Charging Rate. Weigh the SW near the place where it is to be used as fuel. Any SW dropped between the place where it is measured and the place where it is put into the incinerator (and is not recovered) shall be calculated and accounted for. The measurement must be as accurate as equipment and conditions at the HRI permit. Calibrate the weighing scales before and after the test. If the weighing is done on a platform scale, use a dead weight tester to calibrate the scale. For precision calibrating data, use ASME Performance Test Code PTC 19.5 to guide the scale calibration. The following weighing methods are at the contractor's option and are listed in order of decreasing accuracy. Make every effort to use the most accurate method possible. The contractor shall clearly specify the reason for adopting a specific weighing method and shall receive approval from the District Engineer before the test. Clear the tipping floor and/or refuse pit of all SW before the test begins.

Alternative 1. Determine the weight of each charge to the incinerator by weighing each load of material before it is deposited in the charging hopper or the ram chute. This may be accomplished by placing the estimated single charge load of SW into a tarred container resting upon a platform scale (or into a load cell), recording the weight, and then transferring the waste to the charging hopper or the ram chute. Note the weight and number of charges fed into the incinerator each hour.

Alternative 2. Set aside quantities of SW of known weight. Charge the HRI in the normal manner, noting the time each charge is placed in the hopper and the total burning time for the pile of SW. For a continuous feed incinerator, the charging hopper shall be full at the beginning and end of the charging period.

Alternative 3. This method uses average container load weights to determine an average burning rate. Weigh every fifth container load, or one container load per hour (whichever is more frequent), during the test period to determine the average load weight. Record the number of charges during the test period and compute the average burning rate using the average load weight.

Alternative 4. Weigh all incoming SW on the truck scales and place it on the clean tipping floor or in the refuse pit area. Charge the incinerator from this stored SW without recording the weight of each charge. Continue this practice for the test period and record the weight of SW left on the tipping floor or in the pit at the end of the test period. Use the weight of SW received during the 5-day period, the total burning time, and the weight of SW left on the tipping floor or in the pit to calculate the average charging rate to the incinerator. Make every effort to dispose of the daily incoming SW load.

Solid Waste Characterization. The accuracy of the efficiency calculation based on the input-output method depends upon a proximate analysis of the fuel being fired by the HRI. A proximate analysis is accomplished in a laboratory and determines the moisture, volatile matter, fixed carbon, and ash in percent by weight of the "as-fired" SW. Collect samples of incoming SW to determine the physical and proximate chemical constituents. This will identify the combustible and noncombustible elements, moisture content, and high heat value of the composite SW fuel. Take three samples every 24 hr throughout the test period (as described below) and complete the required tests and calculations for each sample.

Because of the variety of conditions under which SW is generated and the heterogeneity of SW, sampling is subject to large errors. Take every precaution to ensure that the samples represent true characteristics of the SW being being fed into the incinerator.

Sampling Procedure: Each sample shall consist of 30 to 40 lb of typical incoming SW as determined by visual inspection. Select a waste analysis processing area convenient to the charging system, but one that will not interfere with the incinerator operation. Determine the density of the incoming SW by weighing each 20- or 30-gal sample container filled with SW. Record the weights and the size of the container.

Waste Analysis Alternatives: The most typical procedure for obtaining an analysis of the waste is to send sealed sample containers to a laboratory. An alternative is to take the samples to an area where they may be sorted into five or six categories whose analysis is well known. The composite analysis is then determined based upon the percentage weights of each of the categories. Although this method is not very accurate, the contractor and the contracting officer may use it to agree that the waste is essentially as indicated in the specification. Consult USA-CERL Technical Report E-75, *Installation Solid Waste Survey Guidelines*, October 1975 (by Gary W. Schanche, Larry A. Greep, and Bernard Donahue) for further details on waste characterization and analysis. Appendix E contains information concerning the method for producing a laboratory proximate analysis, should equipment be available locally.

Liquid Waste Measurements

Any liquid waste (such as crankcase oil) fired in the incinerator during testing shall be representative of the material burned during normal operation. Measure the amount of liquid waste by calibrated weigh tanks, volumetric tanks, or carefully calibrated positive displacement meters. Keep leakage to a minimum; any unavoidable leakage must be calculated and accounted for. When return and supply lines to the burners are used, each flow must be determined.

Collect a representative sample for analysis and higher heating value determination in accordance with ASME PTC 3.1 and ASTM D 240.

Supplementary Fuels Measurements

A modular starved air incinerator may use either a gaseous fuel, such as natural gas, or a liquid fuel, such as oil, to start combustion in the primary chamber and to complete it in the secondary chamber. Measure these fuel flows with an orifice, flow nozzle, dry gas meter (gases), or a positive displacement meter (liquids). Use totalizing fuel flow meters. Calibrate these measuring devices before the acceptance test. Where there is a possibility of contaminants affecting the flow meters, place a filter in the line before the meter.

Take care to ensure flow readings that accurately represent fuel to the incinerator. Avoid fuel leakage. When a fuel return system is used, meter both the supply and return and use the difference for the actual fuel firing rate.

The following data shall be obtained and recorded:

1. Flow rate of burner fuel

2. Inlet temperature of the fuel to the burner

3. Heat input rate to the oil storage tank (when applicable)

4. Temperature of combustion air

5. Burner rating (BTU/hr)

6. Higher heat value of the fuel.

Use only calibrated meters to record auxiliary burner fuel consumption. To calibrate a fuel oil flowmeter, modify the fuel oil pipeline with a tee and provide a valve after the fuel oil meter. This valve will normally be closed. For calibration, measure the normal flow rate of the fuel oil through the piping by collecting the oil flow into a known volume container. Calculate the oil flow rate by clocking the oil flow to the container fill point. Record at least three calibrations. For natural gas fired auxiliary burners, the gas company's flow meter data is acceptable and calibration is not required.

Output Measurements

Determine the output of the Heat Recovery Unit (HRU) by measuring the steam flow output, the steam pressure, and temperature. When the steam is not superheated, use a steam calorimeter to calculate the steam quality. Measure and record the quantity and temperature of the feedwater provided to the HRU. Either measure the boiler blowdown flow or estimate it from the blowdown period.

While there are many methods of measuring the flow rate of a fluid, the accuracy required by ASME PTC 4.1 dictates the use of orifices, flow nozzles, or venturi tubes as primary elements. The differential pressures created by these elements can be converted into flow rates. Regardless of the type of metering elements selected, certain restrictions on their installation exist. One of the most important restrictions is the requirement for certain lengths of pipe with unobstructed flow both upstream and downstream of the metering element. Where this unobstructed length is not available, install a flow straightening vane.

Steam flow meters, such as turbine meters or Vortex flow meters, may be used to measure steam flow rates. Use manufacturers' correction factors when applicable. The contractor shall specify the proposed method for measuring the steam output of the HRU and shall receive approval from the District Engineer before starting the acceptance test.

Measure the quality of the steam (dryness fraction) at saturation temperature with a suitable throttling calorimeter installed and operated in the manner described in ASME PTC 19.11. The saturation steam temperature may be measured at any point in the steam line where convenient, but should be measured as close to the saturation steam outlet as possible.

Residue Measurements

Empty the residue collection pit before starting the acceptance test. During the testing period, put all wet residue in empty residue containers that were weighed before the test. After testing, weigh the containers to determine the total amount of wet residue collected.

Each hour during the testing period, collect representative samples of the wet residue. Use the samples to determine the moisture content according to ASTM D 3176 and D 3180. The moisture content will be used to estimate the total dry ash output and dry ash density. These numbers will then be used to determine the weight and volume reduction of the waste fuel. The residue will also be analyzed for carbon content to determine completeness of combustion.

Stack Emissions Testing:

An HRI installation will generally have four major emission streams:

1. Incinerator and boiler stack gas emission
2. Ash cooling water discharge
3. Ash residue discharge
4. Pit/tipping floor wash water discharge.

Although all waste streams are important, the stack emissions must be tested when the operators start the unit since it is impractical to store these gases like the liquid and solid waste for further evaluation.

A qualified stack gas emission test contractor experienced with EPA Code emission tests shall be hired to conduct these tests. When scheduling permits, the Army Environmental Health Agency (AEHA) may be contacted to conduct these tests. In many states, the stack gas testing report must be certified by a professional engineer licensed in the state. If such certification is required, it is the responsibility of the contractor to have the professional engineer witness these tests.

Whether a contractor or the AEHA conducts the environmental tests, early coordination is imperative. Temporary scaffolding on the stack and supplies of ice and acetone may have to be procured locally. Make every effort to insure that all modifications and adjustments have been made before the environmental testing to ensure that the tests represent what will be typical operating conditions. It is imperative that the environmental tests be run at the same time as the thermal efficiency tests. If the two tests cannot be run concurrently, the environmental test should be run after the thermal testing in case the thermal tests indicate the need for modifications to the HRI. Environmental sampling must be done randomly during each test period to minimize the effect of burning batches of either high or low quality waste and be more representative of all of the waste burned during the test period.

The HRI must comply with Federal codes and regulations specifying emission limits for particulate matter, gaseous pollutants, and smoke, before a certificate for operation is granted. In many states, State or local air pollution codes prevail, even for Federal facilities. Many states are also enacting acid gas control requirements for HRI sizes down to 20 TPD that will have to be complied with. It is the contractor's responsibility to run the emission tests according to the applicable codes (Federal, State, or local).

The particulate emission shall be based on the particulate matter collected by dry filter media and the condensables in an EPA approved sampling train. In some states, the "condensable" portion of the "catch" shall be reported but may not be used to determine compliance with applicable rules. The collected particulates may be used to characterize the total particulate emissions for carbon loss and the trace elements present in the stack gas emissions.

If the HRI is equipped with a dry or wet air pollution control device, such as a baghouse, precipitator, or scrubber, the efficiency of the control device must be determined by taking simultaneous samplings of the gas stream entering and leaving the control device. Many manufacturers of small HRI systems indicate that no air pollution control device is needed for the system. In that case, only stack emission tests are needed.

Smoke emissions shall be based on "opacity" by comparison with the Ringelmann chart issued by the U.S. Bureau of Mines. Certified smoke density readings may be required in some states.

Stack tests for determining particulate matter emissions shall use the EPA 40 CFR, Part 60, Appendix A, and recent revisions thereof, where applicable. All stack emission tests shall be conducted isokinetically and while the HRI is operating at the design or rated maximum charging rate. Particulate testing shall include boiler operation with and without soot blowing. The method of testing during soot blowing shall be in accordance with EPA Code.

Sampling Port Size and Locations. Locate the stack sampling port in the stack where gas flow is relatively uniform across the diameter and at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbances such as bends, expansion or contraction transitions, or visible flame. For stacks of rectangular cross-section, determine an equivalent diameter from the following equation:

$$\text{Equivalent diameter} = 2 \times \frac{\text{length} \times \text{width}}{\text{length} + \text{width}} \qquad \text{[Eq 5]}$$

For stack diameters less than 2 ft, locate the sampling port at least four diameters downstream and two diameters upstream from any disturbances. Where the distances cannot be achieved, a stack extension is required.

To accommodate the gas sampling probes, the contractor must weld 4-in. nominal pipe couplings to the stack sampling ports in positions 90 degrees apart. When welding the pipe couplings to the stack wall, the coupling ends shall not extend past the inside surface of the stack wall any more than is necessary to secure a proper fit.

Traverse Points. The gas sampling traverse axis shall divide the circular stack cross-section into equal parts. For a rectangular stack, divide the cross-section into as many equal rectangular areas as traverse points such that the ratio of the length to the width of the elemental areas is between one and two. Locate traverse points at the centroid of each equal area according to Figure 5. Traverse points shall not be located within 1 in. of the stack wall. Figure 5 illustrates the information needed for traverse points. The following number of points are required:

- For a circular stack with inside diameter (I.D.) between 13 and 24 in., use at least eight traverse points.

- For a circular stack with I.D. less than 13 in., use at least four traverse points.

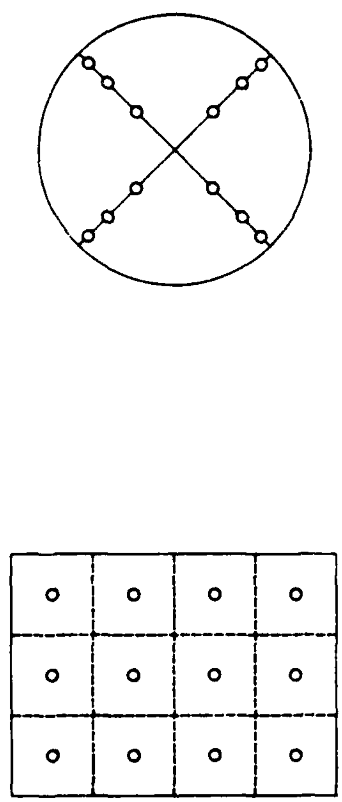


Figure 5. Stack traverse points.

Stack Test Report. The stack test report shall include the following:

1. Introduction.

- Date and location of test

- Description of HRI system tested

- Description of auxiliary fuel burners, including location, type of burner fuel, and actual firing rate (Btu/hr), gas cleaning equipment (if any), overfire fans (locations and cubic feet per minute [CFM]), or other auxiliary equipment in use during the test

- Name of person or authorized agent conducting the test, and Professional Engineer certification if needed.

2. Description of the incinerator operation.

- Type and quantity, by weight, of refuse burned during the test and the frequency of introduction into the incinerator

- Method and duration of preheating period (if any)

- Method and frequency of ash removal during test

- Description of programmed operation such as automatic charging and automatic burner operation.

3. Stack testing and analytical procedures.

- Description and diagram of the sampling train

- Filter designation and specification (fiberglass filter shall be equal to MSA type 1106BH or Gelman type E)

- Detailed discussions of any modifications to EPA test procedure adopted during testing

- Dimensioned sketch of sampling port locations in relation to the stack exit and obstructions to the gas flow near port locations

- Dimensioned sketch of the stack cross-section at sampling port locations illustrating equal areas and sampling points for tests

- Description of method used to determine the weight of particulate catch.

4. Smoke observation.

A record of the smoke readings made during the test. (In some states, certified smoke readers may be requested to read the opacity of the smoke emissions.)

5. Emission Data.

- Tabulation of traverse and sampling data

- Sample computation.

6. Results.

A narrative and tabulated presentation of the stack test results. Results should be expressed in grains per dry standard cubic foot (dscf) at 12 percent CO2, and pounds of particulate per hour vs. pounds per hour of refuse charged, or expressed in pounds of particulate per 100 pounds of refuse charged.

7. Discussion (optional).

State if the particulate emissions meet the applicable standard or code.

Gaseous Pollutant Emissions. For some facilities, especially those located near high environmental pollution areas, regulatory authorities may demand NOx and HCl emissions tests. Because of the low sulfur content of military SW, exemption from SOx emission tests may be granted in most cases. However, for an HRI requiring continuous use of auxiliary burners, NOx emission testing may be mandated by local and State environmental pollution codes and regulations. For most HRI systems, the emission of unburned hydrocarbons and carbon monoxide are important to verify complete combustion and efficient operation of the unit. The contractor shall conduct these tests according to EPA guidelines.

Combustion Air Measurements

While the combustion air flow is not needed to determine the overall system efficiency, this measurement can provide valuable information ensuring that the system is operating as specified. Take pressure measurements at the inlet and outlet of the forced draft fan, in the primary combustion zone, at the exit of the boiler, and (if equipped) at the entrance and exit of the gas cleaning device.

Cooling Water Measurements

Some incinerators have an internal cooling or preheat water system. If this cooling water is kept within the HRI system (i.e., not dumped), its heat content must also be measured if it is considered to be part of the output.

Test Report, Data, and Calculations

Appendix D includes the recommended test report and data and calculation sheets for the input-output method. In some instances, more data are requested than required to complete the test calculations. However, all information listed should be recorded to assure that the system is operating to specification.

Because the data log sheets can be used on many different waste heat recovery incineration systems, the Test Engineer should review the instrumentation and test data log sheets for compatibility of the units of measure. The method of calculating the mass and volume reduction for the HRI is shown on the Test Summary sheet in Appendix D.

4 CONCLUSIONS

A procedure was established for assessing the performance of HRIs in terms of thermal efficiency, weight and volume reduction, environmental emissions, and throughput capacity and reliability.

It was concluded that the input-output method should be used as the basis for the thermal efficiency portion of the acceptance test procedure. The heat-loss method of thermal efficiency determination should be used to isolate the areas of inefficiencies should losses be excessive, and the modified heat-loss method be used for routine monitoring of the system. The calorimeter method should only be used as part of the acceptance test for HRI installations of unit sizes larger than 75 TPD (68 tpd), which is generally beyond starved air size, since that method seems most appropriate for plants of that size and expected sophistication. The alternate concept of separate combustion efficiency and thermal recovery testing should be allowed where appropriate. The acceptance test must be conducted concurrently with environmental testing to assure compliance with air emission standards during normal operation.

APPENDIX A:

RELATED PUBLICATIONS

ANSI Publication

ANSI/ASME B30.2, Overhead and Gantry Cranes (1983).

ASME Power Test Codes Publications

PTC 1, General Instructions (1980).

PTC 3.1, Diesel and Burner Fuels (1958).

PTC 4.1, Steam Generating Units (1964).

PTC 19.2, Pressure Measurement (1964).

PTC 19.3, Temperature Measurement (1974).

PTC 19.5, Application of Fluid Meters (1972).

PTC 19.5.1, Weighing Scales (1964).

PTC 19.10, Flue and Exhaust Gas Analyses (1968).

PTC 19.11, Water and Steam in the Power Cycle (Purity and Quality, Leak Detection and Measurement) (1970).

PTC 33, Large Incinerators (1978).

PTC 38, Determining the Concentration of Particulate Matter in a Gas Stream (1980).

ASTM Publications

D 240, Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (1985).

D 2015, Test Method for Gross Calorific Value of Solid Fuel by the Adiabatic Bomb Calorimeter (1985).

D 3176, Method for Ultimate Analysis of Coal and Coke (1984).

D 3180, Method for Calculating Coal and Coke Analyses from As-Determined to Different Bases (1984).

Corps of Engineers Guide Specifications

CEGS 11171, Incinerators, Packaged Controlled Air (December 1981).

CEGS 11233, Water Softeners, Cation-Exchange (Sodium Cycle) (February 1982).

CEGS 15400, Plumbing, General Purpose (September 1982).

CEGS 15501, Sprinkler Systems, Fire Protection (October 1980).

CEGS 16415, Electrical Work, Interior (April 1985).

CEGS 16721, Fire Detection and Alarm System (October 1985).

EPA Publication

EPA 40 CFR (Code of Federal Regulations), Part 60, Appendix A, Method 5-Determination of Particulate Emissions from Stationary Sources.

Military Specification

MIL-T-52777A, Tanks, Storage, Underground, Glass Fiber Reinforced Plastic (1978).

Underwriters Laboratories

UL 142, Steel Aboveground Tanks for Flammable and Combustible Liquids (1985).

APPENDIX B:

CALCULATIONS THEORY

All sources of fuels are assumed to have the same initial temperature as the entering combustion air which was selected as the reference temperature. However, some supplemental fuels may have to be heated prior to combustion (No. 6 Oil), and that additional heat input must be included.

System Thermal Efficiency by the Input-Output Method

$$\text{Thermal Efficiency (\%)} = \frac{\text{Useful Heat Output}}{\text{Heat Input}} \times 100 \qquad \text{[Eq B1]}$$

$$\nu = \frac{Q_{out}}{Q_{in}} \times 100$$

where:

Q_{in} = Heat from waste + heat from supplemental fuels.

= $\sum$ Mass flow of fuel x heating value of fuels.

= $H_r \times W_r + H_f \times W_f + Hcp \times W_f$.*

Q_{out} = Heat absorbed by the steam and the cooling water (if used).

= $Q_{ye} + Q_{we} = \sum$ Mass flow of steam or water x enthalpy change.

$Q_{ye} = W_{ye} \times (h_{out} - h_{in})$

$Q_{we} = W_{we} \times (h_{out} - h_{in}) = W_{we} \times (t_{out} - t_{in}) \times C_p$.

For water in the range considered, C_p is assumed to be 1.0.

As the name input-output implies, only the energy inputs and the useful energy outputs are measured. The main problem with this method is the difficulty in accurately determining the heat content of the waste. This normally involves collecting large amounts of waste and making the determination based on many laboratory analyses, sorting the waste into its components, or making a visual estimation. This method of efficiency determination is essentially based on the very definition of thermal efficiency. However, it will only indicate that a problem exists; it does not define the problem.

*Symbols are defined in Appendix C.

System Thermal Efficiency by the Heat-Loss Method

$$\text{Thermal Efficiency (\%)} = (1 - \frac{\text{Total Heat Losses}}{\text{Input}}) \times 100 \qquad \text{[Eq B2]}$$

$$\lambda = (1 - \frac{\sum L}{Q_{in}}) \times 100$$

where:

Q_{in} = $H_r \times W_r + H_f \times W_f + H_{cp} \times W_f$

$\sum L$ = Heat losses due to: dry flue gas temperature + unburned CO in flue gas + moisture in waste + hydrogen in waste + spray cooling water + system shell convection and radiation + unburned combustibles in residue + quench water.

$\sum L$ = $L_{G'} + L_{CO} + L_H + L_{H2} + L_{scw} + L_B + L_{UB}$

$L_{G'}$ designates losses due to sensible heat gain of dry combustion gases.

$L_{G'}$ = Mass flow of combustion gases x specific heat of combustion gases x temperature rise of combustion gases through system x ratio of dry combustion gases to total combustion gases.

$$L_{G'} = W_{G'} \times C_p \times (t_{out} - t_{in}) \times 0.98.$$

The ratio of dry combustion gases to total combustion gases is assumed to be approximately 98 percent. For air in the range considered, C_p is assumed to be 0.26.

$$W_{G'} = U_G \times (\text{flue area at outlet}) \times q_{G'} \times 3600$$

$$\gamma_{G'} = \frac{44.01 \times CO2 + 32 \times 02 + 28.01 \times CO + 28.02 \times N2}{1545 \times (460 + t_{out})} \times P \times 144$$

$$N2 = 100 - CO_2 - O_2 - CO$$

L_{CO}= Mass flow of flue gas x mass percent of CO in flue gas x heat of combustion of CO.

$$L_{CO} = 4347 \times W_{CO}$$

$$W_{CO} = \frac{28.02 \times CO}{44.01 \times CO2 + 32 \times 02 + 28.01 \times CO + 28.02 \times N2} \times W_{G'}$$

L_H designates losses due to temperature rise and evaporation of moisture in waste.

L_H = Mass flow rate of fuel x mass percent of moisture in waste x change in enthalpy of moisture.

$$L_H = W_r \times m \times (h_{out} - h_{in})$$

L_{H2} designates losses due to the formation of water through the combustion of hydrogen and subsequent water enthalpy change.

L_{H2} = 9 x mass flow of waste x mass percent of H in waste x water enthalpy change.

$$L_{H2} = 9 \times W_r \times W_{pH} \times (h_{out} - h_{in}).$$

Because 1 mole of H2 produces 1 mole of H2O, 1 lb of H2 produces 9 lb of water during combustion.

L_{scw} designates losses due to the enthalpy change of the spray cooling water.

L_{scw} = mass flow of spray water x change in enthalpy.

$$L_{scw} = W_{scw} \times (h_{out} - h_{in})$$

L_B designates losses resulting from radiant and convective heat losses from incinerator walls.

L_B is based on equipment manufacturer's estimates for the specific facility being tested, usually in the range of 2 to 8 percent of the heat input; for help in simplifying the calculations and data acquisition this was assumed to be 5 percent.

$$L_B = Q_{in} \times 0.05$$

Note: If manufacturer's estimates are not available, and if this assumption is not acceptable, L_B may be approximated as follows:

$$L_B = L_{B1} + L_{B2} + L_{B3} + L_{B4}$$

$L_{Bi} = U_{Bi}$ (surface area) x ($t_{surface} - t_{air}$), and must be calculated for each surface in the incinerator system. (i equals 1, 2, 3, 4, etc.)

L_{UB} designates losses caused by unburned combustibles being rejected in residue.

L_{UB} = Mass flow rate of residue from incinerator x heating value of residue.

$$L_{UB} = W_{res} \times H_{res}$$

The heat-loss method, which is also sometimes (erroneously) referred to as the heat-balance method, is less accurate than the input-output method. This method involves measuring the sensible and latent heat in the flue gas, sensible heat in the ash, combustible material in the ash, radiation and convection from the incinerator and boiler surfaces, latent heat from evaporation of ash quench water, and heat contained in boiler blow-down. This method varies from the calorimeter and input-output methods in that the useful energy output is not measured, but the total heat input is measured and some smaller heat losses may be partially estimated. The accuracy of this method is based on the number of the losses estimated and the accuracy of that estimation.

This method is also affected by the accuracy of the determination of the heat content of the waste and the moisture in the flue gas, which will have a large impact on the gas latent heat losses. The results of a heat-loss determination will never agree (in practice) with the results of the input-output method (based on coal fired boiler experience), although the difference may be as little as 2 percent. This method is preferred by many engineers since it not only indicates the existence of a problem, but it also identifies where the pr_blem is.

System Thermal Efficiency by the Modified Heat-Loss Method

$$\text{Thermal efficiency } (\%) = \left(1 - \frac{\text{Major Losses}}{\text{Heat Input}}\right) \times 100 \qquad \text{[Eq B3]}$$

$$\upsilon = \left(1 - \frac{L_{G'} + L_{UB}}{Q_{in}}\right) \times 100$$

where:

$Q_{in} = H_r \times W_r + H_f \times W_f + H_{cp} \times W_f$

$L_{G'} + L_{UB}$ = Heat losses due to: dry flue gas temperature + unburned combustibles in residue.

$L_{G'}$ = Mass flow of combustion gases x specific heat of combustion gases x temperature rise of combustion gases through system x ratio of dry combustion gases to total combustion gases.

$L_{G'} = W_{G'} \times Cp \times (t_{out} - t_{in}) \times 0.98$.

The ratio of dry combustion gases to total combustion gases is assumed to be approximately 98 percent. For air in the range considered, C_p is assumed to be 0.26.

L_{UB} = Mass flow rate of residue from incinerator x heating value of residue.

$$L_{UB} = W_{res} \times H_{res}$$

The least accurate method is the modified "short form" of the heat-loss determination. This method was proposed by Hecklinger and Grillo in 1982[3] and based on

[3]R. Hecklinger and L. Grillo, pp 65-69.

earlier recommendations by Stabenow in 1980.[4] It is based on the assumption that the major heat loss in the system is up the stack and normally involves taking only O2 and temperature measurements on the stack gases and measuring the fuel firing rate. This is a good assumption for oil/gas fired boilers and is reasonable for most of the larger coal fired boilers where efficient combustion of the fuel is very certain and the amount of moisture in these gases is low and well defined. With the thermal efficiency calculation depending so heavily on so few measurements, the highly variable and generally larger amounts of moisture in the stack gases from an HRI can have a large impact on the results as noted above in the discussion of the heat loss method. Additionally, incomplete combustion of the waste can result in losses as significant as the stack losses as demonstrated by some of the operating instances at Fort Knox and Fort Eustis where labels and other paper goods were readable after going through the incinerator. This can be compensated for by measuring the ash production rate and the carbon content of the ash. Unfortunately, that would make this method almost as complex, but still less accurate than the input-output method. However, this method could be used for day-to-day comparative indications of changes in thermal efficiency that may require more detailed investigation. It could also be used to monitor the results of changes associated with the operating crew and/or maintenance procedures.

System Thermal Efficiency by the Calorimeter Method

$$\text{Thermal efficiency (\%)} = \left(\frac{\text{Useful Heat Output}}{\text{Useful Heat Output + Losses}}\right) \times 100 \qquad \text{[Eq B4]}$$

$$\upsilon = \left(\frac{Q_{out}}{Q_{out} + \sum L}\right) \times 100$$

where:

Q_{out} = Heat absorbed by the steam and the cooling water (if used).

= $Q_{ye} + Q_{we} = \sum$ Mass flow of steam or water x enthalpy change.

$Q_{ye} = W_{ye} \times (h_{out} - h_{in})$

$Q_{we} = W_{we} \times (h_{out} - h_{in}) = W_{we} \times (t_{out} - t_{in}) \times C_p$.

For water in the range considered, C_p is assumed to be 1.0.

$\sum L$ = Heat losses due to: dry flue gas temperature + unburned CO in flue gas + moisture in waste + hydrogen in waste + spray cooling water + system shell convection and radiation + unburned combustibles in residue + quench water.

$$\sum L = L_{G'} + L_{CO} + L_{H} + L_{H2} + L_{scw} + L_{B} + L_{UB}$$

$L_{G'}$ designates losses due to sensible heat gain of dry combustion gases.

[4] G. Stabenow, pp 301-314.

$L_{G'}$ = Mass flow of combustion gases x specific heat of combustion gases x temperature rise of combustion gases through system x ratio of dry combustion gases to total combustion gases.

$$L_{G'} = W_{G'} \times C_p \times (t_{out} - t_{in}) \times 0.98.$$

The ratio of dry combustion gases to total combustion gases is assumed to be approximately 98 percent. For air in the range considered, C_p is assumed to be 0.26.

$$W_{G'} = U_G \times \text{(flue area at outlet)} \times \gamma_{G'} \times 3600$$

$$\gamma_{G'} = \frac{44.01 \times CO2 + 32 \times 02 + 28.01 \times CO + 28.02 \times N2}{1545 \times (460 + t_{out})} \times P \times 144$$

$$N2 = 100 - CO_2 - O_2 - CO$$

L_{CO} = Mass flow of flue gas x mass percent of CO in flue gas x heat of combustion of CO.

$$L_{CO} = 4347 \times W_{CO}$$

$$W_{CO} = \frac{28.01 \times CO}{44.01 \times CO2 + 32 \times 02 + 28.01 \times CO + 28.02 \times N2} \times W_{G'}$$

L_H designates losses due to temperature rise and evaporation of moisture in waste.

L_H = Mass flow rate of fuel x mass percent of moisture in waste x change in enthalpy of moisture.

$$L_H = W_r \times m \times (h_{out} - h_{in})$$

L_{H2} designates losses due to the formation of water through the combustion of hydrogen and subsequent water enthalpy change.

L_{H2} = 9 x mass flow of waste x mass percent of H in waste x water enthalpy change.

$$L_{H2} = 9 \times W_r \times W_{pH} \times (h_{out} - h_{in}).$$

Because 1 mole of H2 produces 1 mole of H2O, 1 lb of H2 produces 9 lb of water during combustion.

L_{scw} designates losses due to the enthalpy change of the spray cooling water.

L_{scw} = mass flow of spray water x change in enthalpy.

$$L_{scw} = W_{scw} \times (h_{out} - h_{in})$$

L_B designates losses resulting from radiant and convective heat losses from incinerator walls.

L_B is based on equipment manufacturer's estimates for the specific facility being tested, usually in the range of 2 to 8 percent of the heat input; for help in simplifying the calculations and data acquisition this was assumed to be 5 percent.

$$L_B = Q_{in} \times 0.05$$

Note: If manufacturer's estimates are not available, and if this assumption is not acceptable, L_B may be approximated as follows:

$$L_B = L_{B1} + L_{B2} + L_{B3} + L_{B4}$$

$L_{Bi} = U_{Bi}$ (surface area) x ($t_{surface} - t_{air}$), and must be calculated for each surface in the incinerator system. (i equals 1, 2, 3, 4, etc.)

L_{UB} designates losses caused by unburned combustibles being rejected in residue.

L_{UD} = Mass flow rate of residue from incinerator x heating value of residue.

$$L_{UB} = W_{res} \times H_{res}$$

This most rigorous method (which is used in Europe) is to use the HRI as a continuous calorimeter. The calorimeter method is much more complex than any of the other methods. It involves doing a complete mass and energy balance around the HRI with the only unknown being the heat content of the waste stream. This involves a very large number of measurements (some of which can be quite tedious, such as heat loss to ash quench water including evaporation) and much more instrumentation than normally found on all but the largest HRI's. Essentially all of the losses associated with the heat-loss method, and the energy output measurements associated with the input-output method must be actually made, and not estimated. If these measurements are made carefully with accurate instrumentation, this method would produce the most accurate results, and avoid the problem of determining the heat content of the waste. However, the measurement of the total moisture of the flue gas is still a major problem at this time, since the traditional EPA Method 5 only involves grab samples. The amount of this moisture can be quite significant if internal sprays are used to cool the combustion zone, the waste is very wet, and/or a quench, ash cooling system is used that is not isolated from the combustion zone. In addition, the potential improvement in accuracy over the input-output method is not significant (0.73 percent)[5] based on the size range and lack of sophistication of typical Army HRI plants.

[5]J. Fernandes.

Due to the complexity involved, the not yet totally resolved question of measuring the moisture in the flue gas, and a relatively small increase in accuracy, this method is not considered appropriate for the size and type of HRI plants the Army would typically build. Starved air technology (the most common type of plant) is not sufficiently developed to warrant this level of accuracy, and additional instrumentation would have to be supplied (at a significant additional cost) for the testing. However, this method would be appropriate to very large (greater than 75 TPD/unit) excess air/"water wall" plants that also might include electrical cogeneration, and would most likely already have all of the instrumentation necessary, and represent both a state-of-the-art and a magnitude of investment that would warrant this level of accuracy and effort. This type of plant would be typical of what the Army would be involved with on a "third party" basis with a local municipality.

APPENDIX C:

SYMBOLS, DEFINITIONS, AND METRIC CONVERSIONS

Symbol Definitions (from ASME PTC 33)

Symbol	Description	U.S. Customary Units	Multi-plier	Equivalent Metric Units
B	Radiation and convection	-	-	-
CO	Carbon monoxide	percent	-	percent
CO'	Carbon monoxide in dry flue gas by volume	percent	-	percent
CO_2	Carbon dioxide in dry flue gas by volume	percent	-	percent
C_p	Specific heat at constant pressure	Btu/lb ^oF	4187	J/kg K
h	Enthalpy	Btu/lb	2326	J/kg
H	Hydrogen	lb/lb	-	kg/kg
H_{cp}	Sensible heat added to supplementary fuels such as No. 6 Oil in order to improve combustion	Btu/lb	2326	J/kg
H_f	Higher heating value (chemical heat) of the supplementary fuel on the "as fired" basis	Btu/lb	2326	J/kg
H_r	Higher heating value of waste (laboratory analysis)	Btu/lb	2326	J/kg
H_{res}	Higher heating value of total dry residue	Btu/lb	2326	J/kg
L	Heat loss from the incineration system	Btu/hr	0.293	W
L_{CO}	Heat loss due to CO in the flue gas	Btu/hr	0.293	W
L_B	Heat loss to radiation and convection	Btu/hr	0.293	W

Symbol	Description	U.S. Customary Units	Multiplier	Equivalent Metric Units
L_H	Heat loss due to moisture in the waste	Btu/hr	0.293	W
L_{H2}	Heat loss due to hydrogen in waste	Btu/hr	0.293	W
$L_{G'}$	Heat loss in dry flue gas	Btu/hr	0.293	W
L_{QW}	Heat loss to quench water	Btu/hr	0.293	W
L_{scw}	Heat loss from the spray cooling water	Btu/hr	0.293	W
L_{UB}	Heat loss to unburned combustibles in residue	Btu/hr	0.293	W
m	Moisture content by weight	percent	-	percent
N	Nitrogen	lb/lb	-	kg/kg
N_2	Nitrogen (gas)	percent	-	percent
O	Oxygen	lb/lb	-	kg/kg
O_2	Oxygen (gas)	percent	-	percent
P	Pressure	psia	6.89	kPa
Q_{in}	Total heat input per unit time	Btu/lb	2326	J/kg
Q_{out}	Total heat output per unit time	Btu/lb	2326	J/kg
Q_{ye}	Heat transferred to recovery liquid (e.g., steam)	Btu/hr	0.293	W
Q_{we}	Heat in water (cooling or quench)	Btu/hr	0.293	W
r	Waste	-	-	-
S	Sulfur	lb/lb	-	kg/kg
t	Temperature	^oF	$(^oF-32)/1.8$	^oC
U	Velocity	ft/s	0.3048	m/s

Symbol	Description	U.S. Customary Units	Multi-plier	Equivalent Metric Units
$U_{G'}$	Velocity of dry flue gas leaving unit	ft/s	0.3048	m/s
V	Volume flow rate	cu ft/min	0.000472	m^3/s
W	Mass flow rate	lb/hr	0.000126	kg/s
W_{CO}	Mass flow rate of CO	lb/hr	0.000126	kg/s
$W_{G'}$	Mass flow rate of dry flue gas leaving unit	lb/hr	0.000126	kg/s
W_f	Mass flow rate of supplementary fuel fired	lb/hr	0.000126	kg/s
W_r	Mass flow rate of waste charged	lb/hr	0.000126	kg/s
W_{res}	Mass flow rate of dry solid residue	lb/hr	0.000126	kg/s
W_{scw}	Mass flow rate of spray cooling water	lb/hr	0.000126	kg/s
W_{we}	Mass flow rate of cooling or preheat water	lb/hr	0.000126	kg/s
W_q	Mass of quench water at start	lb	0.454	kg
W_{ye}	Mass flow rate of steam	lb/hr	0.000126	kg/s
W_p	Weight percent	percent	-	percent
W_{pH}	Weight percent of H in the water	percent	-	percent
β	see B			
γ	Gas specific weight	lb/cu ft	16.0	kg/m^3
$\gamma_{G'}$	Specific weight of dry flue gas leaving unit	lb/cu ft	16.0	kg/m^3
υ	Efficiency	percent	-	percent
'	Dry	-	-	-
$\sum$	Summation	-	-	-

Supplementary Definitions

Air; Combustion:
Air controlled with respect to quantity and direction, supplied through or with a waste/fuel to initiate the burning of combustible material.

Air; Secondary:
Air controlled with respect to quantity and direction, supplied beyond the zone where burning is initiated. This air may be used to complete the burning of combustible materials or to reduce the operating temperature within the incineration system.

Air; Theoretical:
The amount of air (stoichiometric air) required to supply just that oxygen necessary for the complete combustion of a given quantity of a waste/fuel.

Analysis; Proximate:
Laboratory analysis of a fuel sample providing the weight percentages of (1) water or moisture, (2) volatile matter, (3) fixed carbon, and (4) noncombustibles (ash).

Analysis; Ultimate:
Laboratory analysis of a fuel sample providing the composition in weight percentages of noncombustible (ash), moisture, carbon, hydrogen, nitrogen, sulphur, oxygen, and chlorine.

Ash:
Noncombustible mineral matter that remains for complete burning of a waste/fuel sample by a prescribed method.

Baffle:
Any refractory or metal construction intended to change the direction of flow.

British Thermal Unit (Btu):
Defined as 1/180 of the quantity of heat required to raise one pound mass of water from the ice point to the steam point under a constant pressure of one atmosphere.

Burning Rate:
The amount of waste incinerated, usually expressed in mass per unit of burning area per hour.

Capacity; Thermal:
The measured heat input to the system per unit time.

Chamber Volume:
The combustion space of the primary or secondary chamber designed to promote and/or complete combustion.

Charge:
The quantity of waste introduced to the furnace.

Charging Chute:
A passage through which waste materials are fed into an incinerator.

Charging Rate:
The quantity of waste fed to the system per unit of time.

Clinker:
Hard, sintered, or fused pieces formed in the fire by agglomeration of noncombustibles with the possible inclusion of small amounts of combustible material.

Combustion:
The rapid oxidation of combustible material with the resultant liberation of heat.

Draft; Forced:
The pressure above atmospheric created by the action of the fan or blower that supplies air to the system.

Draft; Induced:
The pressure below atmospheric created by the action of a fan, or ejector.

Draft; Natural:
The pressure below atmospheric created by a stack or chimney.

Duct:
A conduit for conveying a gas.

Efficiency; Thermal:
The ratio of heat output to the heat input.

Effluent:
Solid, liquid, or gaseous materials discharged from the system.

Fixed Carbon:
The combustible matter remaining in a sample after heating by a prescribed method.

Fly Ash:
All solids carried in the gas stream.

Flue:
A passage for conducting gaseous combustion products.

Flue Dust:
Any dry filterable material that is or has been airborne (particulate matter) and has been collected.

Flue Gas:
The gaseous products of combustion.

Garbage:
Vegetable and animal wastes from food preparation, cooking, and serving, plus wastes from handling, storage, and sale of produce.

Heat Balance:
An accounting of the heat input and output of the system.

Heat Credits:
Heat credits are those amounts of heat added to the envelope of the incinerator system other than the HHV of the waste and supplementary fuel "As Fired".

Heat Input:
Throughout this procedure, heat input is based on the higher heating value (HHV) of the waste and supplementary fuel and their rates of flow, plus heat credits added by the working fluid or fluids, air, gas and other fluid circuits that cross the system boundary per unit time, or per unit mass. The system boundary encompasses the equipment to be included in the designated "incinerator system". Heat inputs and outputs that cross the system boundary are involved in the efficiency calculations.

Heat Output:
Heat output is based on the heat absorbed by the working fluid or fluids and total heat in the solid, liquid, and gaseous effluents plus heat transferred across the system boundary per unit of time.

Heat Release Rate:
The amount of heat liberated during combustion per unit of time.

Heat Release Rate, Chamber:
The heat liberated per hour, per unit of chamber volume.

Heat Value; Higher:
The total heat liberated per unit mass in a calorimeter corrected to the "As Fired" condition.

Heating Value; Lower:
The total heat liberated per unit mass in a calorimeter minus the latent heat of vaporization of the water.

Incinerator:
A controlled process for burning combustible wastes.

Material Balance:
An accounting of the mass of material entering or leaving the system during the test period.

Metal Oxidation Factor:
This factor accounts for the metals oxidized in the furnace and the combustibles that are removed from the laboratory sample during preparation.

Moisture:
The weight loss when a fuel sample is dried to a constant weight at a temperature from 100 to 105 ^{o}C.

Mol:
Molecular weight of a substance expressed in mass units.

Particulate Matter (Dust):
Any dry filterable material that is or has been airborne.

Primary Chamber:
The portion of the system into which the waste is fed, ignited, and burned under controlled air conditions.

Residue:
Solid materials remaining after passing through the system. This includes fly ash as well as ash and siftings from the burning system.

Rubbish:
All solid waste having combustibles, exclusive of garbage.

Run:
A subdivision of a test consisting of a complete set of observations made for a period of time with one or more of the independent variables maintained virtually constant.

Secondary Chamber:
The portion of the system where additional air and fuel are added to complete the combustion process (sometimes referred to as an after burner section).

Siftings:
That solid material that falls through the grates.

Smoke:
The visible discharge, other than water vapor, from the system to the atmosphere.

Stack:
A chimney or a vertical flue for discharging the gaseous products of combustion from the system to the atmosphere.

Stack Dust:
Airborne solid material that exits to the atmosphere with the flue gas.

Supplementary Fuel:
Fuel burned to supply additional heat to the system.

Test:
The word "test" as defined in this report applies to the entire investigation.

Volatile Matter:
The weight loss of a dry sample on heating by a specified method without combustion taking place.

Waste:
Any solid, semi-solid, liquid, or gaseous material discharged from its primary use.

APPENDIX D:

TEST REPORT AND DATA AND CALCULATION SHEETS

HRI Acceptance Test Summary

Facility ______________________________

1. Unit Identification: ______________________________

2. Contractor: ______________________________

3. Incinerator Manufacturer: ______________________________

4. Test Engineer: ______________________________

5. Environmental Contractor: ______________________________

6. Analytical Laboratory: ______________________________

7. Army Witness: ______________________________

I PRE-TEST

8. Test Engineer familiar with Test Data required? ______________

9. Deviations from requirements approved by District Engineer? ______________

10. Written verification of inspections and preliminary testing provided? ________

11. Arrangements for three 24-hr runs within five days? ______________

II ACCEPTANCE TEST*

	SPEC COMPLIANCE				Pass
12. Run Number		1	2	3	
13. Date					
14. Run Start Time					
15. Run End Time					
16. Steady State Achieved (Yes, No)					
17. Waste Throughput (T/D) $\geq$(5) x (6)/2,000					
18. Thermal Output Flow Rate (lb/hr) ($\geq$14)/24					

*Calculation numbers refer to test data sheet.

19. Thermal Output Pressure (PSI_) ______ ______ ______ ______ ____
(11)

20. Thermal Output Temperature (^{o}F) ______ ______ ______ ______ ____
(12)

21. Waste Mass Reduction (%) ______ ______ ______ ______ ____
100 - (38)

22. Waste Volume Reduction (%) ______ ______ ______ ______ ____
100 - (39)

23. Acceptable Air Emissions (Yes,No) ______ ______ ______ ______ ______

24. Thermal Efficiency (%) ______ ______ ______ ______ ______
(35)

25. Equipment Specifications Met(Yes,No)______ ______ ______ ______

HRI Acceptance Test Data and Calculation Sheets

Facility ______________
Run No. __________

Item						
1. Date	_____	_____	_____	_____	_____	_____
2. Time	_____	_____	_____	_____	_____	_____
3. Ambient Temperature (°F)	_____	_____	_____	_____	_____	_____
4. Duration of Test Interval (hr)	_____	_____	_____	_____	_____	_____
I FUEL INPUT						
5. Charges Delivered	_____	_____	_____	_____	_____	_____
6. Average Wt. of Each Charge (lb)	_____	_____	_____	_____	_____	_____
7. Liquid Waste Consumed (gal)	_____	_____	_____	_____	_____	_____
8. Auxiliary Fuel Consumed(ft^3, gal)	_____	_____	_____	_____	_____	_____
9. Fuel Oil Temperature (°F)	_____	_____	_____	_____	_____	_____
II THERMAL OUTPUT						
10. Water Inlet Temperature (°F)	_____	_____	_____	_____	_____	_____
11. Outlet Pressure (PSI_)	_____	_____	_____	_____	_____	_____
12. Outlet Temperature (°F)	_____	_____	_____	_____	_____	_____
13. Outlet Steam Enthalpy (BTU/lb) (from calorimeter)	_____	_____	_____	_____	_____	_____
14. Outlet Flow (gal, lb)	_____	_____	_____	_____	_____	_____
III RESIDUE OUTPUT						
15. Total Wet Residue (lb)	_____	_____	_____	_____	_____	_____
16. Weight of Wet Residue Sample(lb)	_____	_____	_____	_____	_____	_____
17. Weight of Dried Residue Sample(lb)	_____	_____	_____	_____	_____	_____
18. Volume of Dried Residue Sample(ft^3)	_____	_____	_____	_____	_____	_____
19. FD Fan Pressure (inches)	_____	_____	_____	_____	_____	_____
20. Primary Zone Pressure (inches)	_____	_____	_____	_____	_____	_____
21. Boiler Exit Pressure (inches)	_____	_____	_____	_____	_____	_____
22. Gas Cleaning Entrance Pressure (inches)	_____	_____	_____	_____	_____	_____
23. Gas Cleaning Exit Pressure (inches)	_____	_____	_____	_____	_____	_____

24. Primary Zone CO Content (%) ____ ____ ____ ____ ____ ____

25. Stack CO Content (%) ____ ____ ____ ____ ____ ____

V CALCULATIONS

26. Waste Fuel Heating Value (BTU/lb) (from analysis) ____ ____ ____ ____ ____ ____

27. Liquid Waste Heating Value (BTU/gal) (from analysis) ____ ____ ____ ____ ____ ____

28. Aux. Fuel Heating Value (BTU/ft^3, gal) (from supplier or table) ____ ____ ____ ____ ____ ____

29. Sensible Fuel Heat Input (BTU/lb) ((9)-(3)) x 0.53 ____ ____ ____ ____ ____ ____

30. Waste Through-Put (TPD) (5) x (6) x 24/((4) x 2000) ____ ____ ____ ____ ____ ____

31. Total Heat Input (MBTU) ____ ____ ____ ____ ____ ____
((5) x (6) x (26) + (7) x (27) + (8) x (28) + (7 or 8) x (29) x 7.2) / 10^6

32. Water Enthalpy (BTU/lb) (from table and (10)) ____ ____ ____ ____ ____ ____

33. Output Enthalpy (BTU/lb) (from (11), (12), and (13)) ____ ____ ____ ____ ____ ____

34. Total Heat Output (MBTU) ((33) - (32)) x (14)* / 10^6 ____ ____ ____ ____ ____ ____

35. Thermal Efficiency (%) 100 x (34)/(31) ____ ____ ____ ____ ____ ____

36. Residue Moisture (decimal) 1-((17)/(16)) ____ ____ ____ ____ ____ ____

37. Density of Refuse (lb/ft^3) (from analysis) ____ ____ ____ ____ ____ ____

38. Refuse Residual Weight (Dry) (%) 100 x (1- (36)) x (15)/((5) x (6)) ____ ____ ____ ____ ____ ____

39. Refuse Residual Volume (%) 100 x (15) x (18) x (37)/((16) x (5) x (6)) ____ ____ ____ ____ ____ ____

40. Carbon Content of Ash (%) (from analysis) ____ ____ ____ ____ ____ ____

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*Change to lb at water inlet temperature if expressed as gal.

APPENDIX E:

SOLID WASTE LABORATORY ANALYSIS

USA-CERL Technical Report (TR) E-75, *Installation Solid Waste Survey Guidelines*, October 1975 (by Gary W. Schanche, Larry A. Greep, and Bernard Donahue) should be consulted for details on waste characterization, sampling, sample preparation, and analysis. The tests described below can only be performed after the raw samples have been shredded, mixed, and reduced to smaller representative samples by coning as described in TR E-75. No current equipment is capable of performing these tests on large, bulk quantities of waste, and they are normally performed on many small representative increments of waste that have been finely shredded. Although the tests described below are normally performed in a laboratory, they may be performed at the site if suitable equipment and trained personnel are available.

Moisture Test

The moisture content of samples of combustible and noncombustible waste shall be determined by laboratory analysis the same day samples are collected, if possible. It is very easy for the sample to gain or lose moisture to its surroundings. Each sample bag shall be suitably tagged for identification including date and time the sample was taken. The laboratory test procedure shall be as follows:

- The entire sample shall be placed in pans and weighed.

- The tarred pans and their contents shall then be dried to a "constant-weight" in an appropriately sized mechanical convection oven at 221 °F.

- From the initial and final "constant-weight" data, the weight of moisture lost in the drying oven will be calculated. The laboratory data entry and calculation of the percentage of moisture level of the total field sample shall be performed as shown on the Refuse Characteristics data sheet in this Appendix.

Volatiles Test

SW is known to generally have a very high volatiles content due to the greases, oils, and large amount of other organic materials. The object of this test is to drive off these volatiles without any significant oxidation of the fixed carbon. The laboratory test procedure shall be as follows using the dried sample from the moisture test:

- Each sample shall be carefully weighed in its pan.

- The tarred pans and their contents shall then be heated in an appropriately sized mechanical convection oven at 1742 °F for seven minutes.

- From the initial and final weight data, the weight of volatiles lost in the oven will be calculated. The laboratory data entry and calculation of the percentage of volatiles of the total field sample shall be performed as shown on the Refuse Characteristics data sheet in this Appendix.

Fixed Carbon Test

The object of this test is to determine the amount of carbon remaining in the SW after the volatiles are driven off. This is done by burning the carbon in an Electric Muffle Furnace per ASTM D 3174. This furnace shall be provided with the means of maintaining an air flow rate of 2 to 4 volume changes per minute distributed uniformly over the furnace area. The test is normally performed using 1-gram samples placed in a porcelain capsule. The laboratory test procedure shall be as follows, using material from the volatiles test:

- The sample material will be pulverized to pass through a No. 60 (250 mm) sieve.

- Each 1-gram sample will be weighed to the nearest 0.1 mg and placed into the porcelain capsule.

- The capsule will be placed in the cold furnace which will then be heated gradually to reach 1290 to 1380 °F in 2 hours.

- These temperatures shall be maintained for an additional 2 hours to burn off all of the carbon.

- The capsule will then be removed from the furnace, covered, allowed to cool under conditions that minimize moisture pickup, and then weighed.

- If unburned carbon particles are observed, or if duplicate results are suspect, the samples should be returned to the furnace for sufficient time to reach a constant weight (+/- 0.001 g).

- From the initial and final weight data, the weight of carbon lost in the oven will be calculated. The laboratory data entry and calculation of the percentage of fixed carbon of the total field sample shall be performed as shown on the Refuse Characteristics data sheet in this Appendix. The final weight of the sample will also be used to calculate the ash content.

HRI Refuse Characteristics

Facility _______________

1.	Date						
2.	Time						
3.	As Received Sample Wt. (lb)						
4.	As Received Sample Vol. (cu ft)						
5.	Dry Sample Wt. (lb) (dried at 221 ^{O}F)						
6.	Volatilized Sample Wt. (lb) (heat to 1742 ^{O}F for 7 minutes)						
7.	Burned Sample Wt. (lb) (burned in air at 1382 ^{O}F or greater)						
8.	Heat Content (Btu/lb) (dried sample burned in calorimeter and adjusted for moisture)						
9.	As Received Density (lb/cu ft) (3)/(4)*						
10.	Moisture Content (%) 100 x (1-(5)/(3))						
11.	Volatile Content (%) 100 x ((6) - (5))/(3)						
12.	Fixed Carbon Content (%) 100 x ((6) - (7))/(3)						
13.	Ash Content (%) 100 x (7)/(3)						

*Replace the numbers in parentheses with the value of the indicated step.

APPENDIX F:

EXAMPLE PERFORMANCE EVALUATION AND ACCEPTANCE TEST

HRI Acceptance Test Summary

Facility Fort Anywhere

1. Unit Identification: No. 2
2. Contractor: Conservation Environmental
3. Incinerator Manufacturer: Refuse Leader
4. Test Engineer: Mr. Present
5. Environmental Contractor: AEHA
6. Analytical Laboratory: Lo-Cal Labs
7. Army Witness: Mr. Post

I PRE-TEST

8. Test Engineer familiar with Test Data required? Yes
9. Deviations from requirements approved by District Engineer? Yes
10. Written verification of inspections and preliminary testing provided? Yes
11. Arrangements for three 24-hr runs within five days? Yes

II ACCEPTANCE TEST*

	SPEC COMPLIANCE				Pass
12. Run Number		1	2	3	
13. Date		1 AUG	3 AUG	5 AUG	
14. Run Start Time		0700	0700	0700	
15. Run End Time		0655	0655	0655	
16. Steady State Achieved (Yes, No)		Yes	Yes	Yes	
17. Waste Throughput (T/D) $\geq$(5) x (6)/2,000	25	25.2	24.8	25.1	Yes
18. Thermal Output Flow Rate (lb/hr) ($\geq$14)/24	7,173	7,230	6,997	7,321	Yes

*Calculation numbers refer to test data sheet.

19. Thermal Output Pressure (PSIG) (11)	125	125	125	125	Yes
20. Thermal Output Temperature (°F) (12)	353	353	353	353	Yes
21. Waste Mass Reduction (%) 100 - (38)	68	83.5	80.2	79.8	Yes
22. Waste Volume Reduction (%) 100 - (39)	85	85.9	89.2	88.7	Yes
23. Acceptable Air Emissions (Yes,No)	Yes	Yes	Yes	Yes	Yes
24. Thermal Efficiency (%) (35)	60	60	59	61	Yes
25. Equipment Specifications Met (Yes,No)	Yes	Yes	Yes	Yes	

HRI Acceptance Test Data and Calculation Sheets

Facility Fort Anywhere
Run No. 1

1. Date	1 AUG	1 AUG	1 AUG	2 AUG	2 AUG	
2. Time	0700	1300	1900	0100	0655	
3. Ambient Temperature (°F)	72	85	73	60	65	
4. Duration of Test Interval (hr)	-	6	6	6	6	
I FUEL INPUT						
5. Charges Delivered	0	83	81	80	82	
6. Average Wt. of Each Charge (lb)	0	158	154	148	157	
7. Liquid Waste Consumed (gal)	0	0	0	0	0	
8. Auxiliary Fuel Consumed(ft^3, ~~gal~~)	0	2379	2268	2155	2337	
9. Fuel Oil Temperature (°F)	N/A	N/A	N/A	N/A	N/A	
II THERMAL OUTPUT						
10. Water Inlet Temperature (°F)	220	220	220	220	220	
11. Outlet Pressure (PSIG)	125	125	125	125	125	
12. Outlet Temperature (°F)	353	353	353	353	353	
13. Outlet Steam Enthalpy (BTU/lb) (from calorimeter)	1193	1194	1192	1193	1194	
14. Outlet Flow (~~gal~~, lb)	0	43002	43865	42955	43698	
III RESIDUE OUTPUT						
15. Total Wet Residue (lb)	0	3,328	3,166	3,005	3,267	
16. Weight of Wet Residue Sample(lb)	0	10	10	10	10	
17. Weight of Dried Residue Sample(lb)	0	6.4	6.6	6.3	6.7	
18. Volume of Dried Residue Sample(ft^3)	0	0.37	0.42	0.36	0.35	
19. FD Fan Pressure (inches)	N/A	N/A	N/A	N/A	N/A	
20. Primary Zone Pressure (inches)	-0.1	-0.1	-0.1	-0.1	-0.1	
21. Boiler Exit Pressure (inches)	-0.3	-0.3	-0.3	-0.4	-0.4	
22. Gas Cleaning Entrance Pressure (inches)	-	-	-	-	-	
23. Gas Cleaning Exit Pressure (inches)	-	-	-	-	-	

24.	Primary Zone CO Content (%)	N/A	N/A	N/A	N/A	N/A	
25.	Stack CO Content (%)	< 5	< 5	< 5	< 5	< 5	
V	CALCULATIONS						
26.	Waste Fuel Heating Value (BTU/lb) (from analysis)	5600	5600	5600	5600	5600	
27.	Liquid Waste Heating Value (BTU/gal) (from analysis)	0	0	0	0	0	
28.	Aux. Fuel Heating Value (BTU/ft^3, gal) (from supplier or table)	1031	1031	1031	1031	1031	
29.	Sensible Fuel Heat Input (BTU/lb) ((9)-(3)) x 0.53	0	0	0	0	0	
30.	Waste Through-Put (TPD) (5) x (6) x 24/((4) x 2000)	0	26.2	24.9	23.7	25.7	
31.	Total Heat Input (MBTU) ((5) x (6) x (26) + (7) x (27) + (8) x (28) + (7 or 8) x (29) x 7.2) / 10^6	0	75.89	72.19	68.53	74.50	
32.	Water Enthalpy (BTU/lb) (from table and (10))	188	188	188	188	188	
33.	Output Enthalpy (BTU/lb) (from (11), (12), and (13))	1193	1194	1192	1193	1194	
34.	Total Heat Output (MBTU) ((33) - (32)) x (14)*/ 10^6	0	43.26	44.04	43.17	43.96	
35.	Thermal Efficiency (%) 100 x (34)/(31)	0	57	61	63	59	
36.	Residue Moisture (decimal) 1-((17)/(16))	0	0.36	0.34	0.37	0.33	
37.	Density of Refuse (lb/ft^3) (from analysis)	16	14	15	13	17	
38.	Refuse Residual Weight (Dry) (%) 100 x (1- (36)) x (15)/((5) x (6))	0	16.24	16.75	15.99	17.00	
39.	Refuse Residual Volume (%) 100 x (15) x (18) x (37)/((16) x (5) x (6))	0	13.15	15.99	11.88	15.10	
40.	Carbon Content of Ash (%) (from analysis)	0	5	6	5	6	

*Change to lb at water inlet temperature if expressed as gal.

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